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**Paper No. 12B: Model Testing  
of an Oval Shaped Seal for  
Sealing of Large Gaps Between  
Mating Surfaces**

U.S. DEPARTMENT OF THE NAVY  
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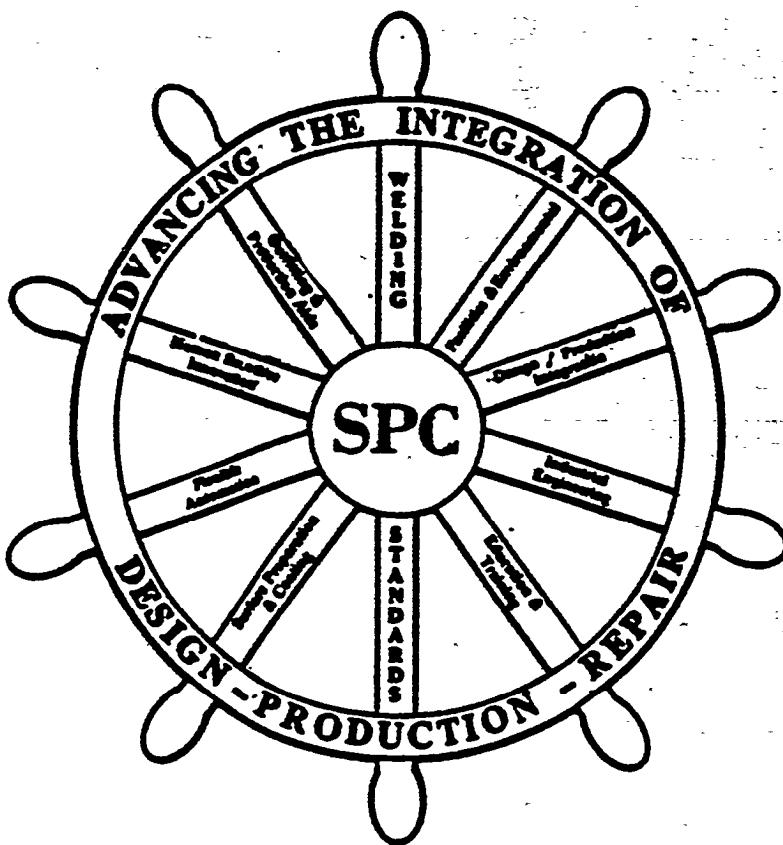
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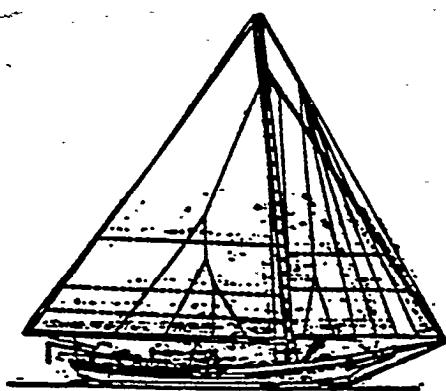
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# Model Testing of an Oval Shaped Seal for Sealing of Large Gaps Between Mating Surfaces

No.128

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## ABSTRACT

A pressure chamber was designed and manufactured in two parts which were clamped together at their flanges using a clamping ring and an "O" ring seal was used for sealing the gap between the mating surfaces. The clamping ring held the two flanges together while the chamber was pressurized with mixed gas. The internal chamber pressure caused the gap to widen (unseat with pressure) resulting in a final gap in which the "O" ring could no longer maintain an adequate seal. The "O" ring seal groove was designed with an undercut or dovetail groove to capture the "O" ring. The dovetail groove cross-sectional area was designed to accept 100 percent of the "O" ring area. The pressure chamber could not be taken out of service to redesign the mating connection and to accomplish the related production work. To solve this problem, an oval shaped seal was designed to fit into the existing dovetail groove, but with a greater standoff height to allow for the larger gap (See Figure 1).

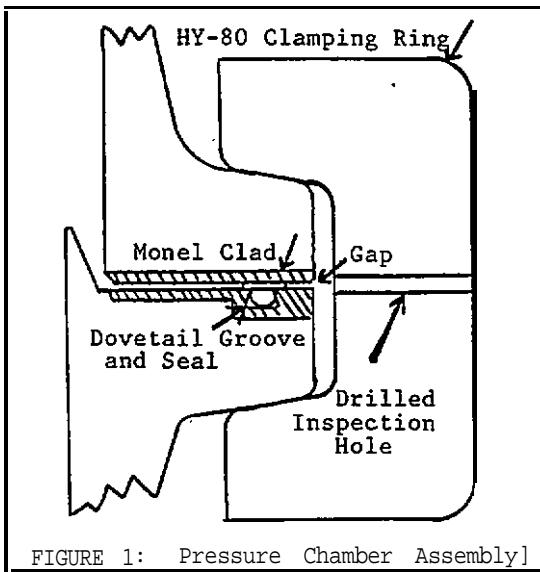


FIGURE 1: Pressure Chamber Assembly

## INTRODUCTION

The oval shaped seal cross sectional area was designed to be equal to that of the existing "O" ring. The oval seal was of a non-standard design and had no previous performance data. A test program was needed and developed to certify the seal for this application by (1) obtaining field data on actual gaps at the seal area of the chamber, (2) applying the field parameters to model testing. The material selected for the oval seal was EPDM Neoprene Military Specification MIL-G-22050 with a Shore A durometer hardness of 80. The criteria for material selection was based on (1) operating pressure, (2) operating temperature, (3) permeability (tendency of gas to diffuse through the elastomer), (4) service life, (5) static application and (6) extrusion resistance.

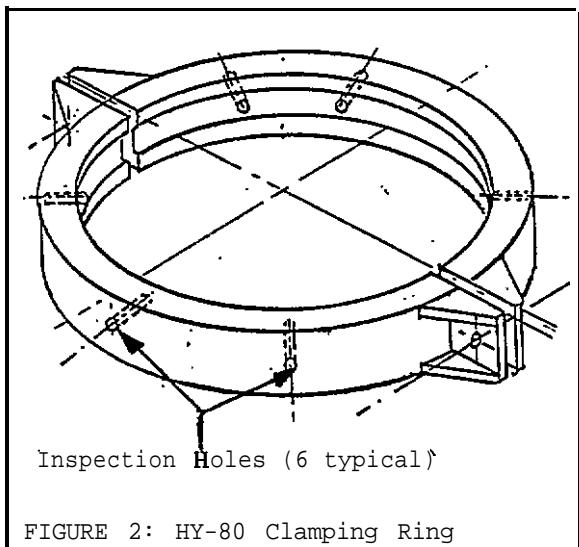
## FIELD DATA

Actual field data was considered necessary to identify seal test parameters and criteria for model testing and seal certification for this specific application. Direct gap measurements of the pressure chamber were taken to (1) determine relative waviness/unevenness between flanges (measurements taken every five degrees circumferentially with seal and clamping ring removed), (2) determine gaps with seal installed before clamping (measurements taken every five degrees circumferentially), (3) direct measurements with clamp in position. The measurements for (1) and (2) could be easily obtained because the mating surfaces were exposed however, once the clamping ring was installed, the mating surfaces were obstructed and direct measurements were no longer achievable. This presented a problem as the maximum unseating gap occurred under internal pressure and this measurement was needed for correlation to model testing.

### Direct Measurements With Clamp Installed

The solution to obtaining these measurements originated with a finite

element analysis of the HY-80 material clamping ring. The finite element model depicted internal forces and geometry of the ring. Stress plots/contours were developed to determine stress gradient across the HY-80 clamping ring. As a result, it was concluded that six 3/8 inch diameter inspection holes could be drilled through the center of the 2-1/2 inch thick clamping ring without compromising safety of design (See Figure 2). The inspection holes were to be used for direct access to measure the actual gaps with clamping ring installed and system at full operating pressure. The rationale for inspection hole location was based on accessibility for drilling, expected areas of high deflection and the location of areas of greatest unevenness between mating flanges. The gaps were first measured with the system unpressurized and then fully pressurized to directly measure the increase due to unseating pressure. The gaps were measured by inserting a specially designed feeler gage through the inspection holes to directly measure gaps on the low pressure side of the oval seal.



#### Field Data Obtained for Model Testing

The field data taken demonstrated that without a seal installed, unevenness existed between mating surfaces ranging from 0 inch (metal to metal) to .009 inch. After the oval seal installation without clamping ring installed, gaps between mating surfaces ranged from .025 inch to .045 inch. With oval seal and clamping ring installed and no internal pressure, gaps measured from .020 inch to .040 inch. Under full pressure, the gaps measured through the inspection holes were .020 inch to .057 inch. The range of percent squeeze

of the oval seal under pressure are as follows:

<u>.051 Inch</u>	<u>.020 Inch</u>
.350 Seal Height	.350
-.222 Dovetail Groove Height	-.222
-.128 Seal Standoff Height	-.128
-.057 Max. Gap	Min. Gap -.020
.071 Squeeze	squeeze .108
<b>% Squeeze = .071/.350 = 20% Minimum</b>	
<b>% Squeeze = .108/.350 = 30% Maximum</b>	

It is to be noted that the commercial recommended squeeze for "O" ring seals ranges from 20-35 percent. (Reference Parker Hannifin Corporation O-ring Handbook ORD-5700.) ASTM recommends 25 percent squeeze for proper sealing.

#### Original "O" Ring Failure

As can be demonstrated from the above unseating gap data, the original "O" ring could not withstand full pressure without leaking due to improper squeeze of the "O" ring. This is attributable to the built-in surface unevenness plus the increasing gap due to unseating pressure. This can be best illustrated as follows:

Original "O" ring diameter .269 Inch Min.  
Depth of dovetail groove-.222 Inch Max.  
Standoff Height of "O" Ring .047

With 20 percent of the circumference of the chamber having an actual unseating gap of .040 inch to .057 inch, it is clear why the existing "O" ring would not properly seat under operating pressure.

#### MODEL AND TESTING APPROACH

Technical discussions were held in which it was concluded that for oval seal certification, a test fixture would be designed and manufactured with a 1/4 scale overall diameter (approximately 11 inches) yet maintain the full scale cross-sectional area of dovetail groove and oval seal (See Figure 3).

#### Test Fixture

The test fixture was designed of two flat circular shaped plates bolted together. Stress and deflection calculations performed indicated that the top and bottom plates to be constructed of HTS (high tensile steel per MIL-S-22698 Grade DH) plate of 1-1/2 inches and 2 inches thick respectively. The bottom plate would have machined in it, the dovetail seal groove, the oval seal and passages for filling and venting the assembled fixture (See Figure 4).

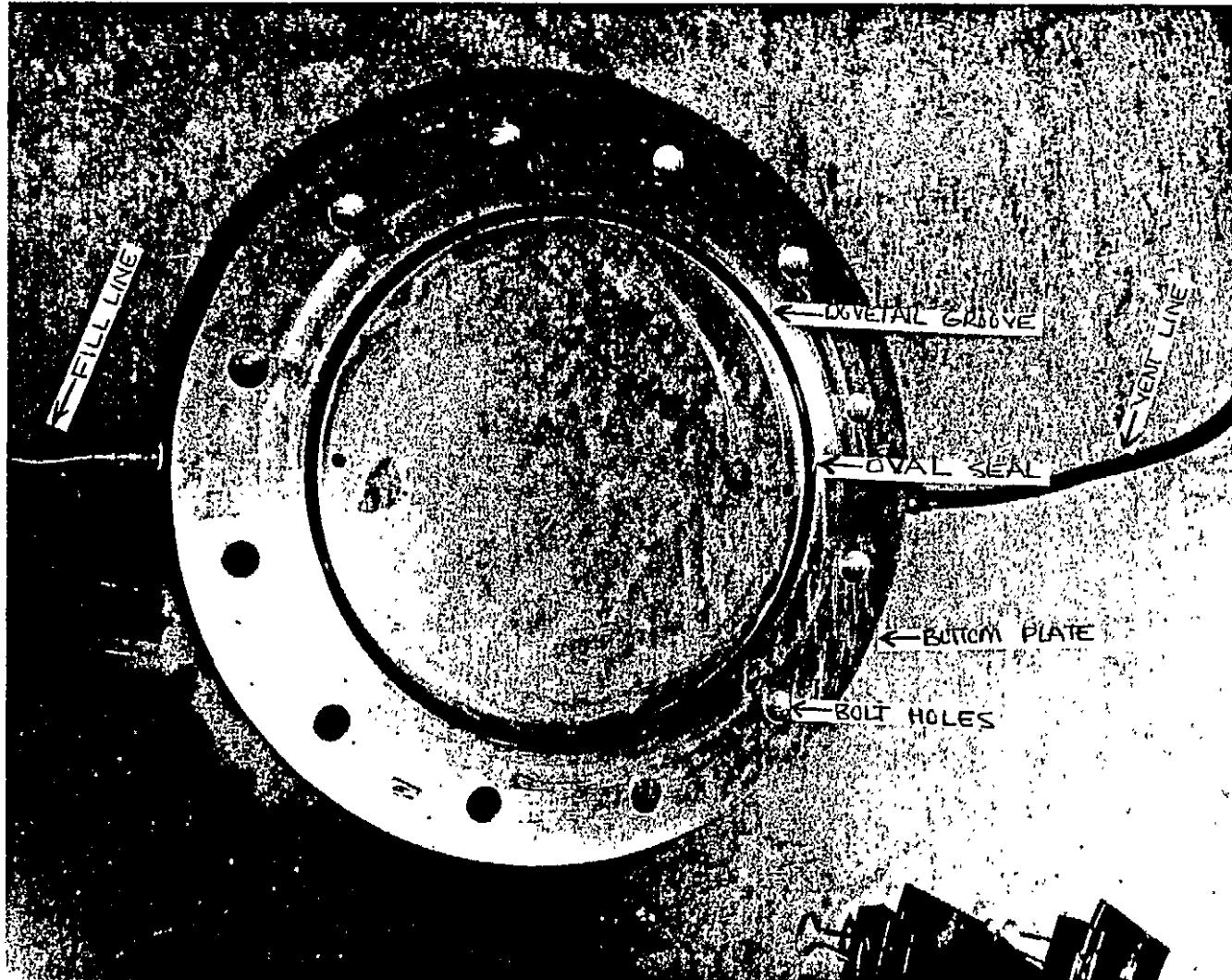


FIGURE 4: TEST FIXTURE BOTTOM PLATE

The plates would be held together by twelve attachment bolts and were designed to be 3/4 inch-10 UNC machine bolts Grade 8 per MIL-S-001222 (See Figure 5 and Figure 6). The bolts would be sequentially torqued to 185 ft. lbs to assemble the fixture for testing. The geometry of the gland seal area including surface finish, would be to the same drawing requirements as the full size pressure chamber. In addition, in order to directly view the seal shape at the smallest measured gap, a second top plate was manufactured of clear Plexiglas (per MIL-C-24449) that would mate to and accommodate the same method of attachment to the bottom steel plate.

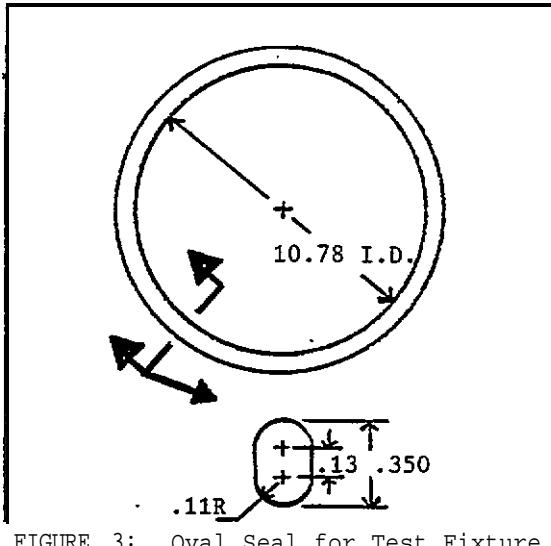


FIGURE 3: Oval Seal for Test Fixture

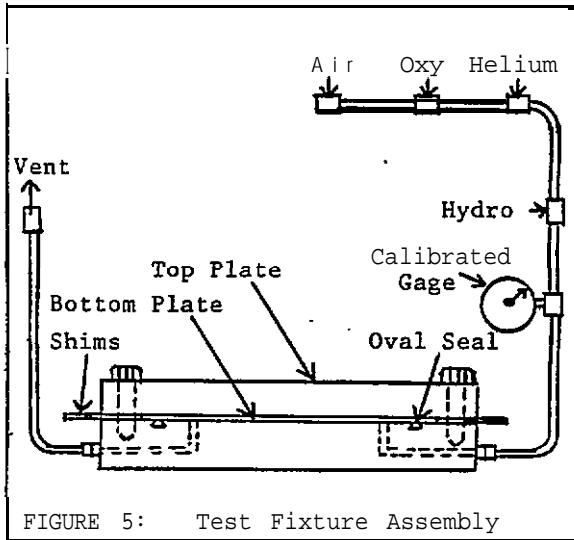


FIGURE 5: Test Fixture Assembly

#### Gap Control

Shims were designed to fit in-between the top and bottom plates and in-between the attachment bolts in order to directly control test gap. The shims were milled out of steel plates of various thickness from .002 inch to .064 inch.

#### Criteria for Model Testing:

Technical discussions were held on operational parameters from which the following test criteria was developed:

1. Initial Test Pressure = 1512 psig (1450 psig minimum)
2. A helium and oxygen mixture would be used for final testing.
3. Test temperatures=+140 degrees fahrenheit, -40 degrees fahrenheit.
4. Ten day pressurized hold test at each temperature extreme.
5. A cyclic, seal stiffness and visual compression test would be required.

#### MODEL TESTING

##### Hydrostatic Test

In order to determine the maximum gap the oval seal would hold for start of testing program, pressure and gap iterations were performed of the test fixture with oval seal installed. This was accomplished by internally pressurizing the test fixture with water and varying the gap (shim pack) starting with .080 inch gap and incrementally decreasing the gap (See Figure 7). At .075 inch gap, the oval seal in the test fixture held the full 1512 psig. Results were then verified by installing a second oval seal which sustained the same pressure at the same gap. The gap of .075 inch was then used to proceed with the remainder of the test program.

##### Low Temperature Mixed Gas Test

A new oval seal (Shore A Hardness = 79) was installed in the test fixture using the .075 inch gap previously determined by hydrostatic testing. The test fixture was placed into an environmental test chamber and subjected to -40 degrees fahrenheit (See Figure 8). Upon pressurizing the system with a 80 percent helium 20 percent oxygen gas mixture, leakage occurred at 800 psig. Upon disassembly investigation revealed that excessive fluoralube grease was present on the top plate's mating surface directly

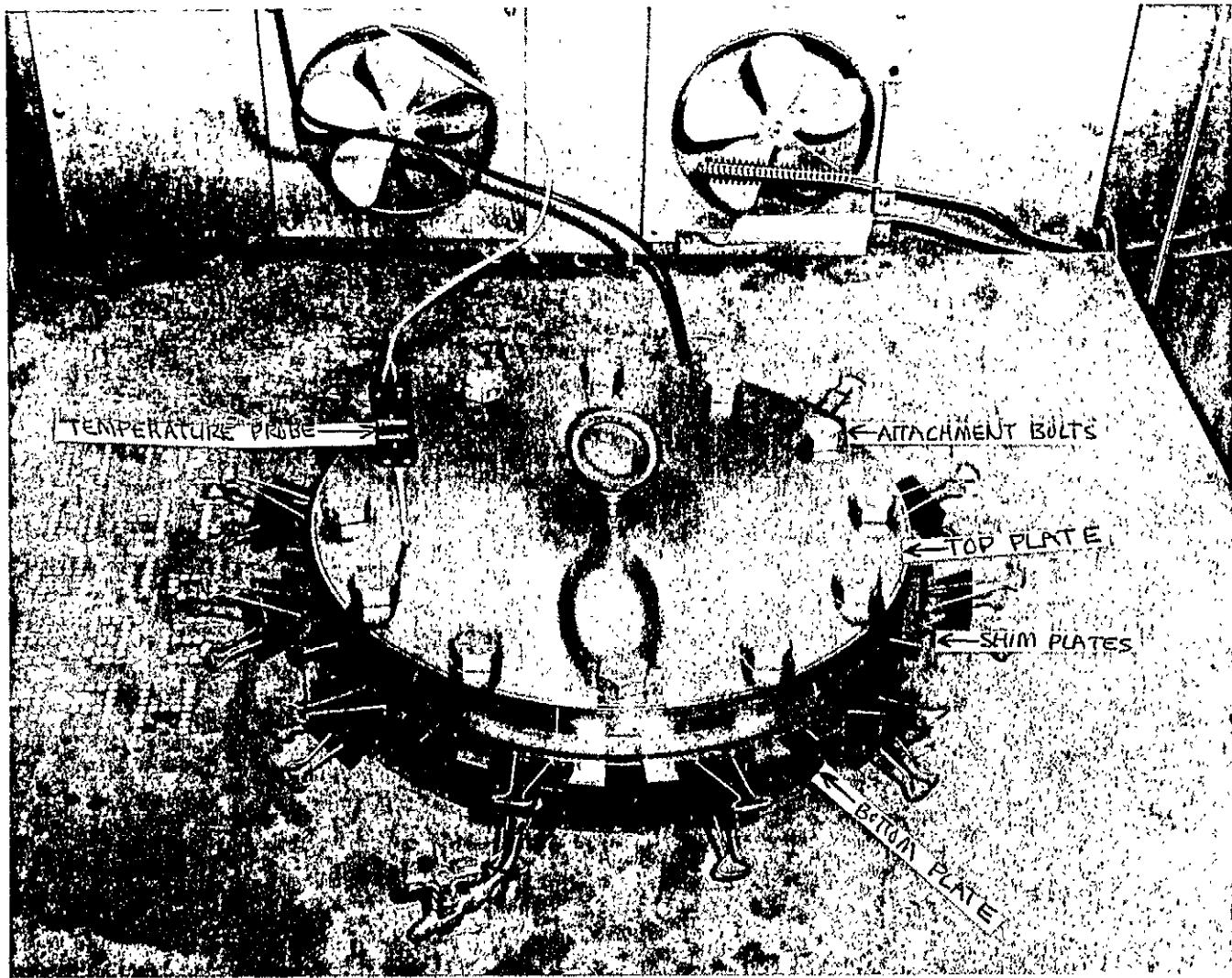


FIGURE 6: TEST FIXTURE ASSEMBLY

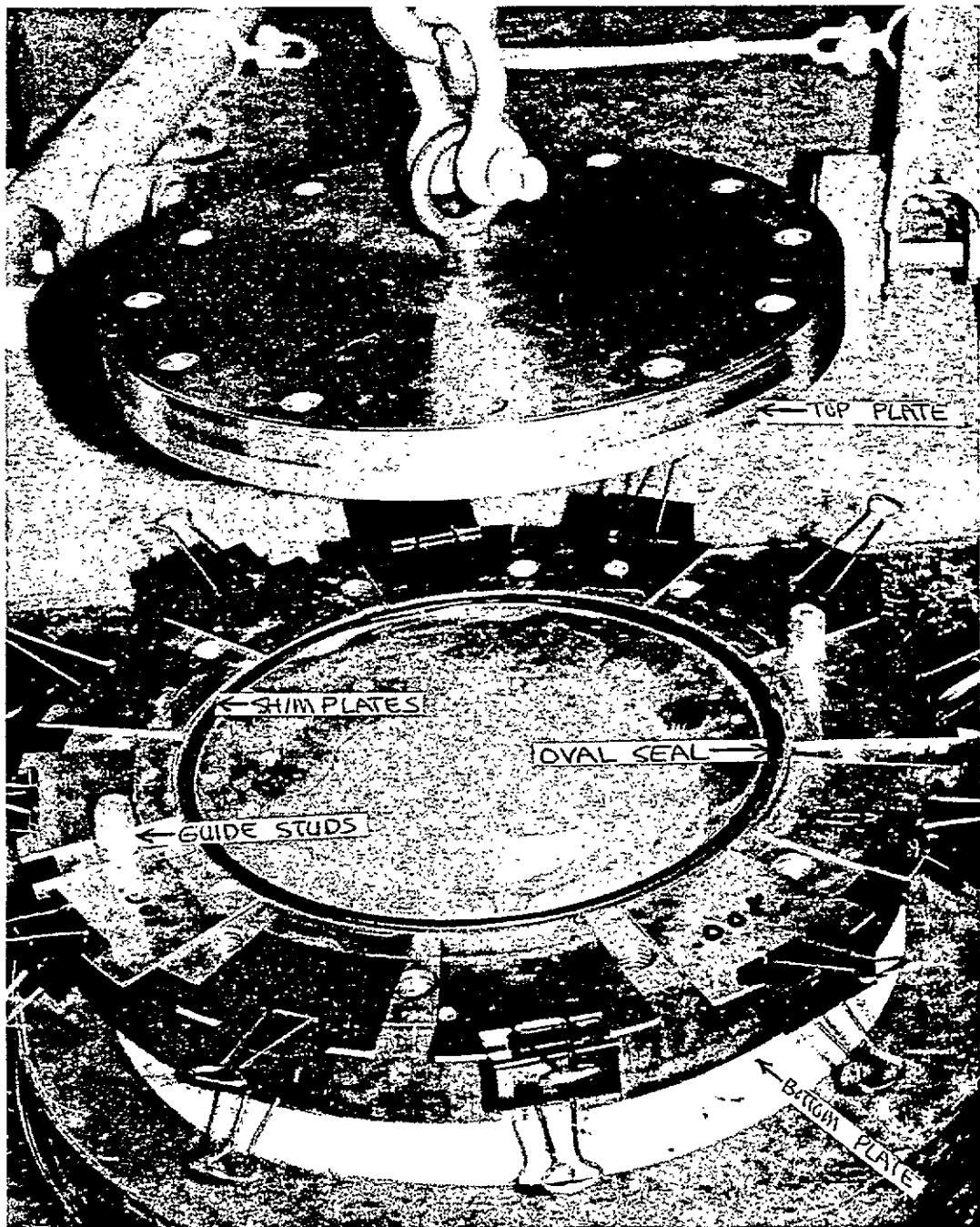


FIGURE 7: HYDROSTATIC TEST-FIXTURE DISASSEMBLED

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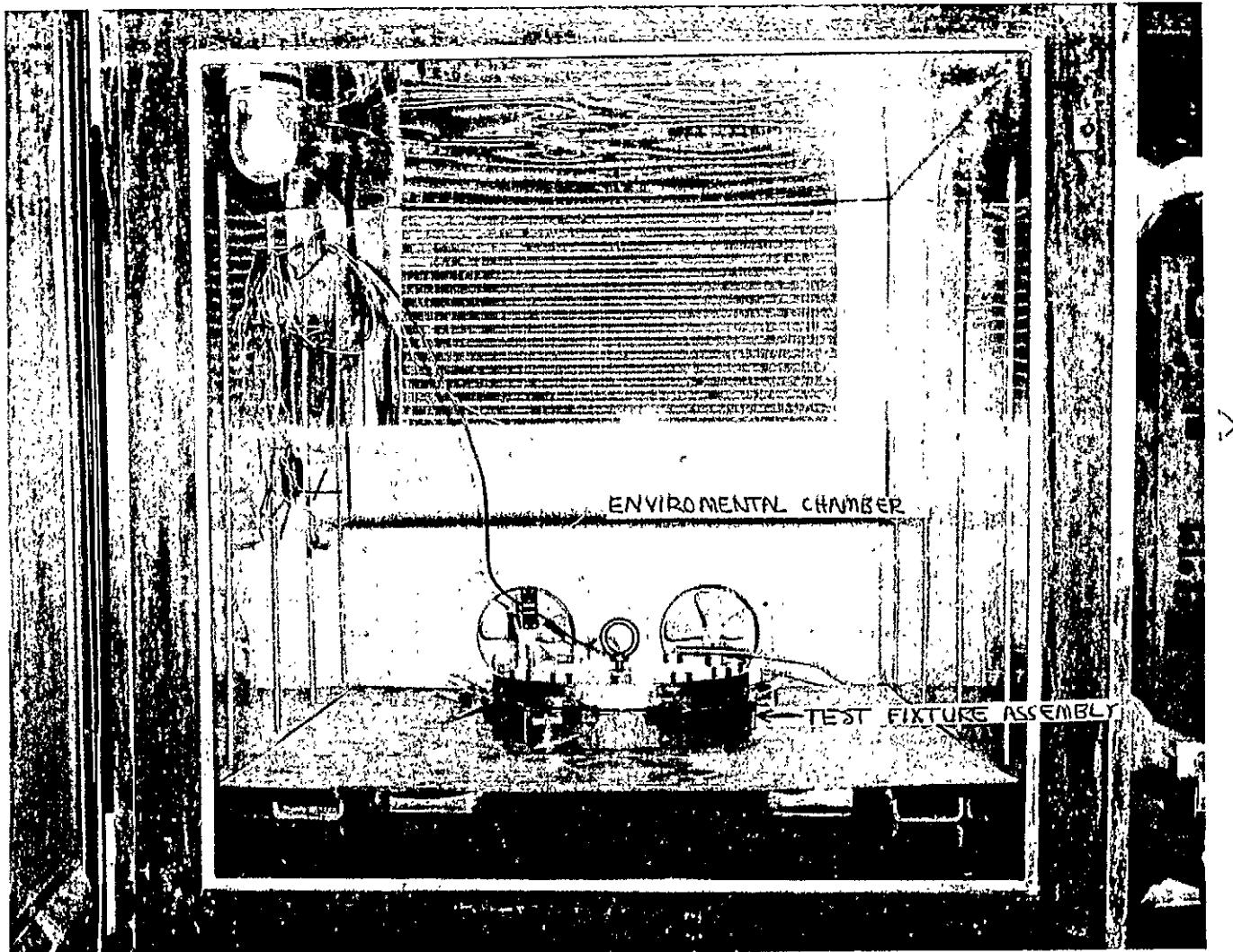


FIGURE 8: TEST FIXTURE IN ENVIRONMENTAL CHAMBER

above the oval seal, allowing mixed gas to leak by. The fluoralube grease was originally used to lubricate the oval seal for ease of installation into the dovetail groove. The excessive grease was wiped off, the fixture reassembled, cooled to -40 degrees fahrenheit and again pressurized. This time the pressure of 1512 psig was attained and then held for the ten day test period. Temperature and pressure were continuously recorded and checked every eight hours during the test period. Total pressure loss over the ten day period was 9 psig. At the completion of the ten day test, the test fixture was removed from the environmental chamber and disassembled. The oval seal was visually inspected and exhibited a slight amount of compression set however, there was no damage to the sealing surface and the oval seal was still considered serviceable.

#### High Temperature Mixed Gas Test

A new oval seal (Shore A Hardness = 79) was installed into the test fixture using the previously established .075 inch gap (shim pack). The test fixture was placed into the environmental chamber and heated to +140 degrees fahrenheit and the system pressurized with the 80 percent helium and 20 percent oxygen gas mixture. No pressure drop was encountered therefore the 10 day/240 hour hold test commenced. The test pressure and temperature was continuously checked every eight hours during the test period. At 184 hours (76 percent) into the test the pressure had dropped below the specified minimum of 1450 psig to a value of 1447 psig and make-up gas was added to restore the 1512 psig. The test was then continued to the ten day completion at which time the final pressure was 1492 psig. The pressure drop throughout the ten day test was linear and at a rate of -.36 psig/hour. The test fixture was removed from the environmental chamber and disassembled. The oval seal was removed and examined under 10X magnification. The oval seal had shown evidence of having taken a permanent set after being compressed and pressurized. Although the set was greater than noticed on previous oval seal tests, the oval seal did not exhibit major damage and was still considered serviceable. The pressure loss of 8.6 psig/day developed during the test was attributed to gas diffusion through the gasket as opposed to a seal boundary leak which would have steadily increased until system failure.

#### Cyclic Hydrostatic Pressure Test

A new oval seal (Shore A Hardness = 79) was installed into the test fixture at the previously established

.075 inch gap (shim pack). The test fixture was subjected to 199 cycles of water pressure cycling from 0 psig to 1512 psig then back to 0 psig. Each 30 second cycle consisted of:

1. Eight second duration-increase pressure from 0 to 1512 psig.
2. Ten second duration-hold 1512 psig pressure.
3. Twelve second duration-decrease pressure from 1512 psig to 0 psig.

At the completion of the 200 cyclic testing, the pressure level was brought up to 1512 psig and held for ten minutes then returned to zero. The test fixture was then disassembled and the oval seal removed for visual inspection. Inspection revealed that the oval seal exhibited permanent set from being compressed, however, there was no evidence of cuts, nicks or extrusion and the oval seal was considered as still serviceable.

#### Stiffness/Load Deflection Test

A new oval seal (Shore A Hardness = 79) was installed in the test fixture which was then placed in a 60 ton hydraulic press. The hydraulic press held the test fixture plates together in lieu of the attachment bolts. Two dial indicators were positioned to monitor the relative movement between the upper and lower test fixture plates (See Figure 9). A compression load was then applied in 1000 pound increments from 0 pounds to 10,000 pounds then decreasing to 0 pounds. Dial indicator readings were recorded and plotted at each 1000 pound increment (See Figure 10) .

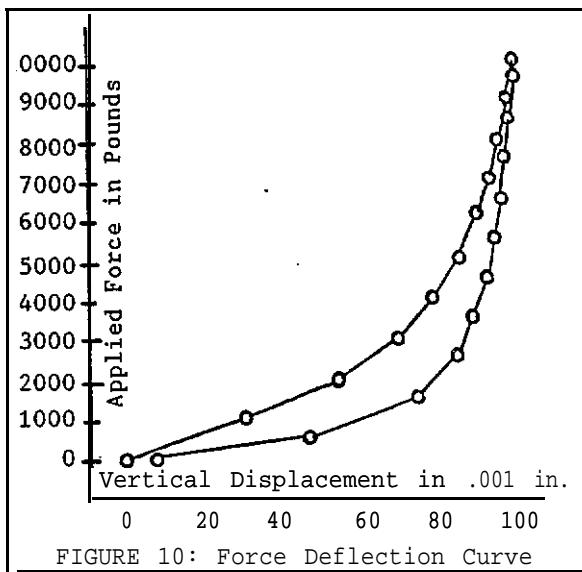


FIGURE 10: Force Deflection Curve

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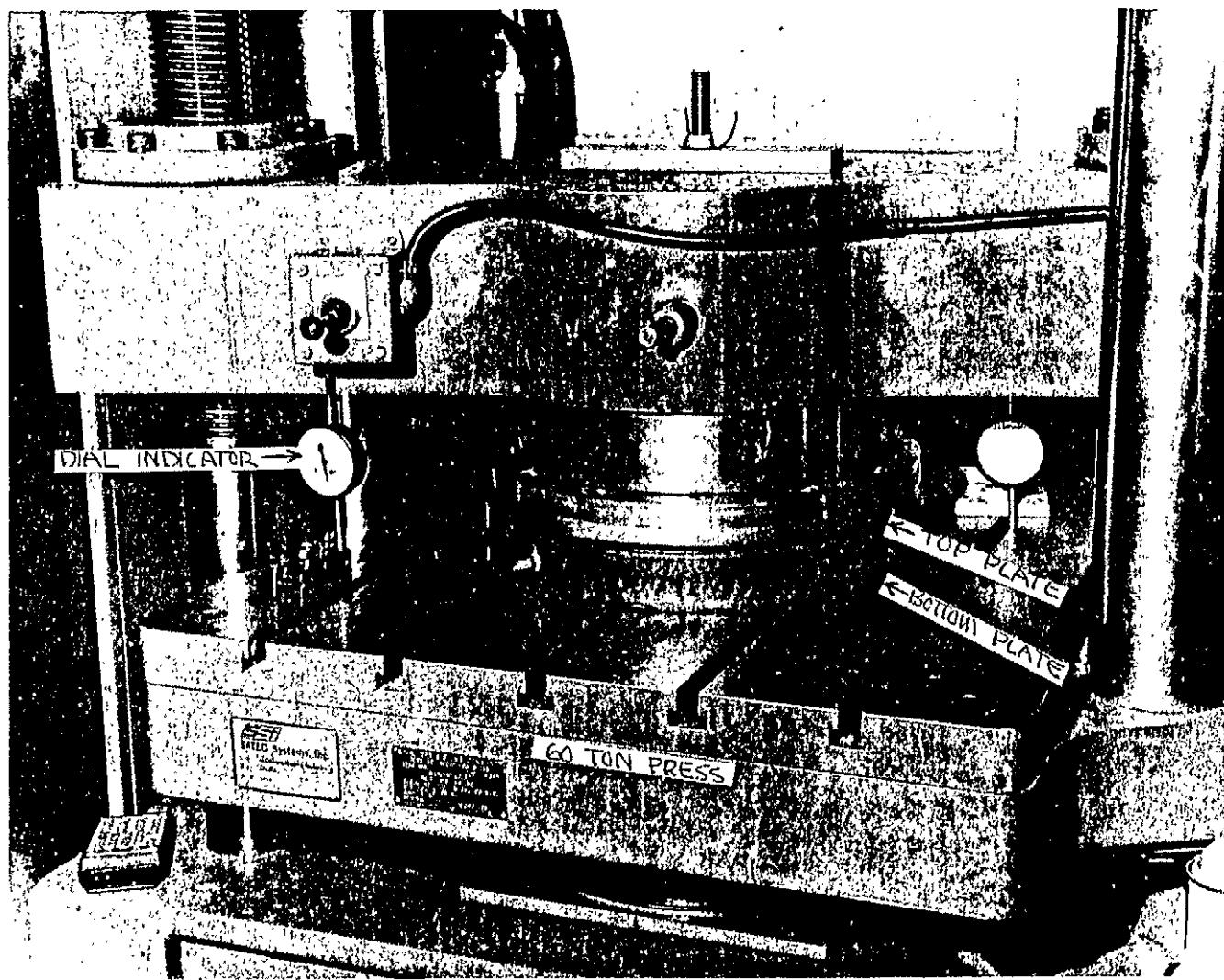


FIGURE 9: TEST FIXTURE IN HYDRAULIC PRESS

### Visual Compression Test

A new oval seal was installed in the dovetail groove in the lower plate of the test fixture. The steel top plate of the test fixture was replaced with the 2-1/2 inch thick polished Plexiglas plate (See Figure 11). The shape of the oval seal was visually observed and photographed through the transparent plate. The attachment bolts were progressively tightened to reduce the gap between plates to .020 inch which corresponded to the minimum measured chamber gap. The final gap of .020 inch was fixed by installing shims between the plates. The behavior of the seal was observed and photographed through the transparent plate (See Figure 12). The results of the test indicate that when the gap is decreased the oval seal does not recede into the dovetail groove but deforms to a mushroom shape to seal the gap between the two plates. At the completion of the test, the fixture was disassembled. The oval seal was visually inspected and considered to be in satisfactory condition.

### CONCLUSION

The oval shaped seal technically met the intent of the test program, therefore, it has been recommended for use in the full size pressure chamber. The pressure loss which occurred during the high temperature test was significant for the small volume (8 cubic inches) of the model test fixture but insignificant when scaled to the much larger volume (many cubic feet) of the full size test chamber. The following recommendations were imposed as a part of operational use of the oval seal:

1. Operational pressure not to exceed approximately 400 psig.
2. Operation pressure gap between mating surfaces not to exceed .060 inch (measured with special feeler gage).
3. Operational temperature envelope of -40 degrees fahrenheit to +140 degrees fahrenheit.
4. Replace seal after 200 cycles of use or after one year.
5. Visually inspect seal after every use.
6. Install oval seal in dovetail groove using a light film of lubrication.

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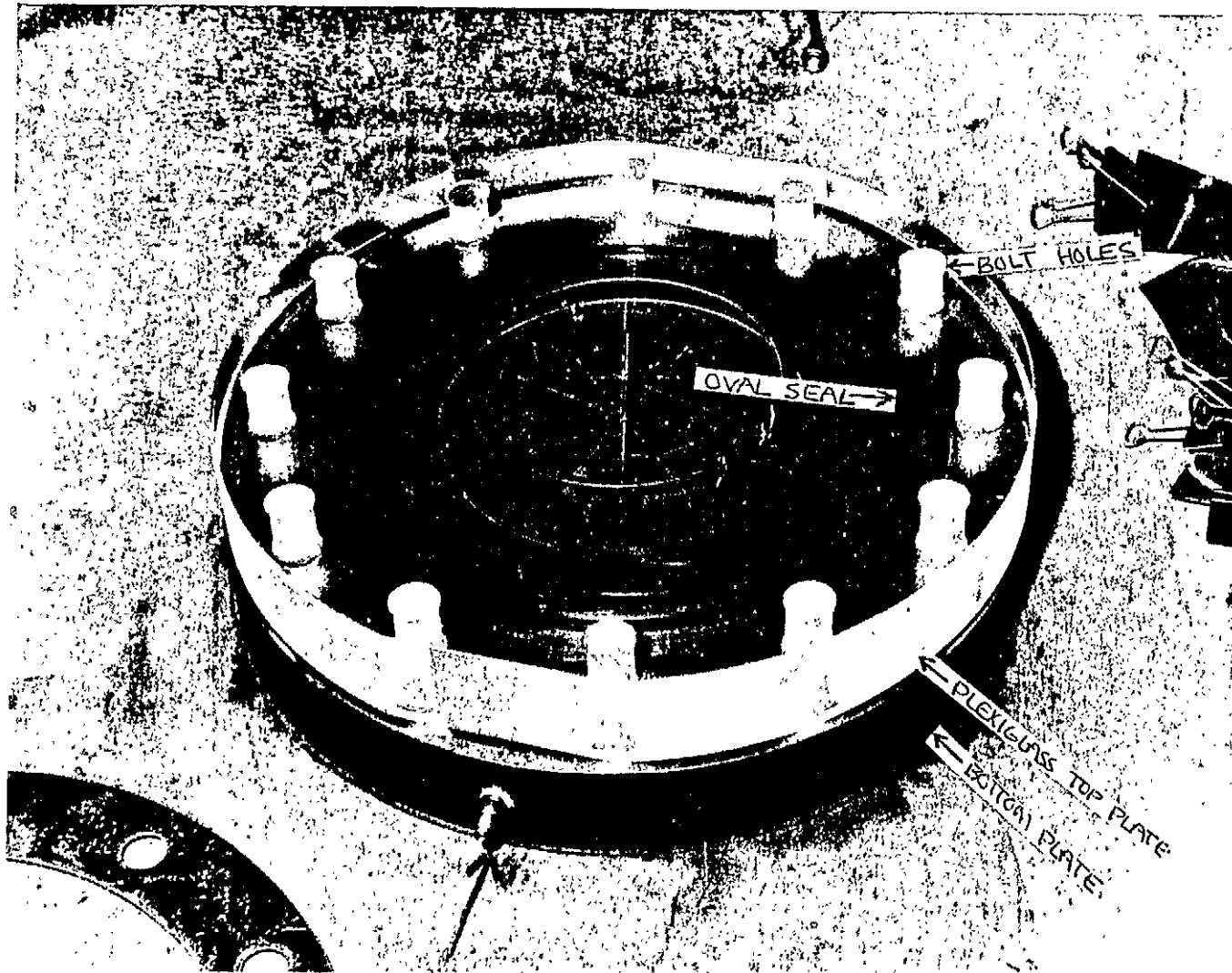


FIGURE 11: TRANSPARENT PLEXIGLAS TOP PLATE

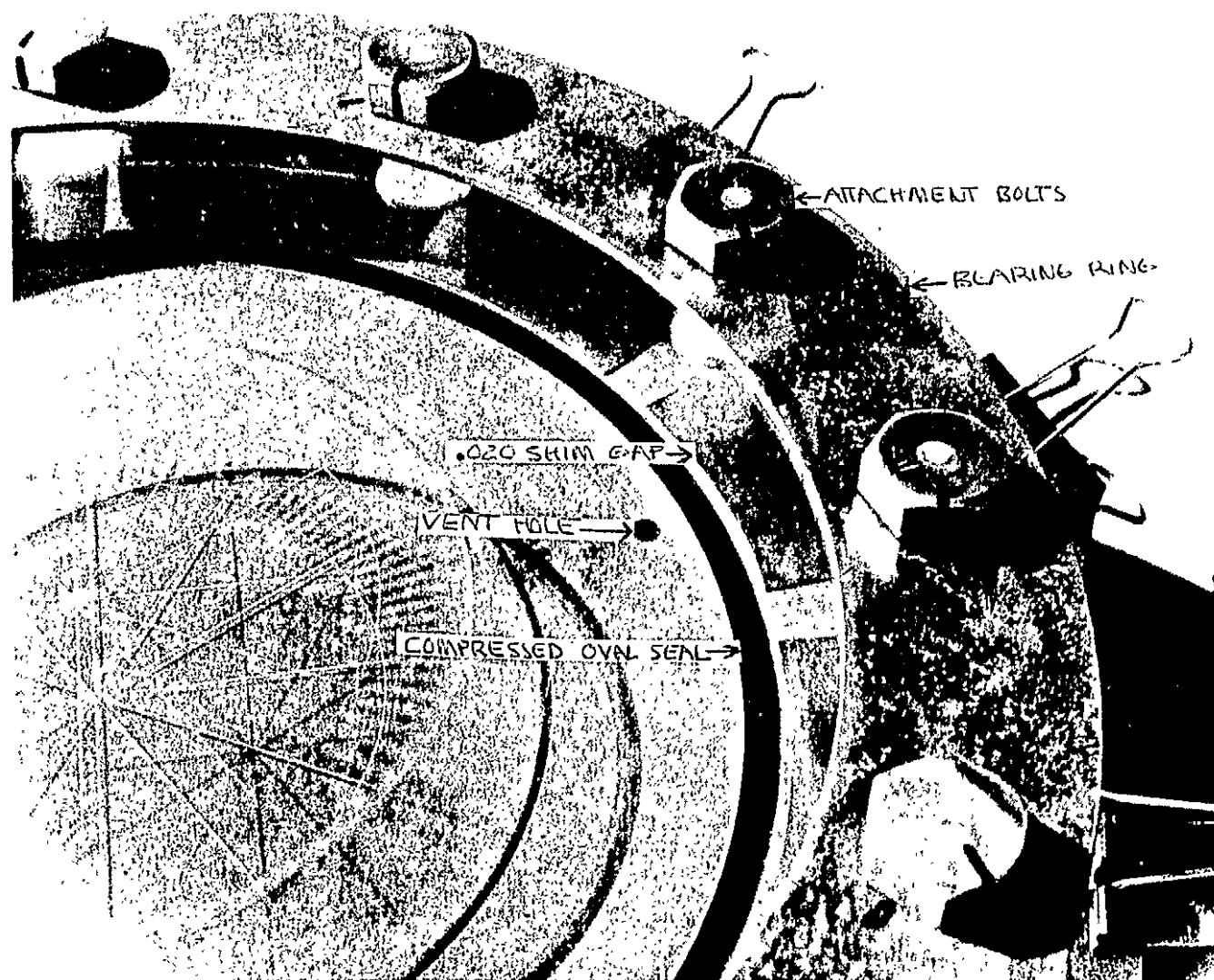


FIGURE 12: TOP VIEW OF COMPRESSED OVAL SEAL

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